REMARKS

This paper responds to the Office Action dated December 3, 2001.

Claims 1-36 were pending at the time of the Office Action. Claims 1-36 have been canceled and new claims 37-71 have been added. The new claims correspond roughly with the old claims as follows:

old	1, 9	2	3	4	5	6	7	8	10
new	37	38	39	40	41	42	43	44	45

old	11	12	13	14	15	16	17	18	19
new	46	47	48	49	50	51	52	53	54

old	20	21	22, 9	23	24	25	26	27	28
new	55	56	57	58	59	60	61	62	63

old	29	30	31	32	33	34	35	1, 9, 36
new	64	65	66	67	68	69	70	71

Claim Rejections 35 USC §112

Claims 16 and 27. The Examiner rejected claims 16 and 27 as supposedly indefinite. The Examiner stated that he was unclear as to the structure used for cavity dumping.

It is respectfully suggested that "cavity dumping" is a method of coupling out radiation from a laser cavity. An acousto-optic device is suddenly switched on, by which a beam path out of the cavity is provided, so that energy is nearly instantly dumped from the laser cavity. It is further respectfully suggested that "cavity dumping" has a definite and well-known meaning in the art. Attached please find a copy of an extract from a standard solid-state laser textbook, namely W. Koechner, Solid-State Laser Engineering, 5th ed., (Springer-Verlag, Berlin, 1999). In the extract, cavity dumping is explained.

Reconsideration of the rejection of claims 16 and 27 is thus respectfully requested.

Claim 36. The Examiner rejected claim 36 as supposedly indefinite, being a method claim depending from an apparatus claim (claim 1). New claim 71 has been introduced which is intended to correspond with former claim 36, incorporating limitations from former claims 1 and 9. Claim 71 does not depend from any other claim.

Claim Rejections 35 USC §103

The former independent claims were claims 1, 22, and 36. New independent claims 37, 57, and 71 are now present. Each of these claims incorporates the subject matter of former claim 9.

In the office action, the Examiner stated that the subject matter of the former claims 1 and 22 as well as of some dependent claims was made obvious over Kasamatsu et al. (Applied Optics, Laser-Diode-pumped Nd:YAG active mirror laser, "Kasamatsu") and Weingarten et al. US Pat. No. 5,987,049 ("Weingarten"). It is respectfully suggested that the subject matter of the new independent claims is not made obvious by the cited references.

Kasamatsu shows a thin-disk laser, the thin-disk laser medium being mounted on a cooling surface. However, Kasamatsu shows a *continuous-wave* (cw) laser (see page 1879, second column), and *not a laser for emitting pulsed electromagnetic radiation* as in the claimed

preamble

invention.

The requirements for continuous-wave lasers differ in many aspects from the requirements for of pulsed lasers. Whereas the cavity of cw lasers is designed to provide a monochromatic, coherent output beam, in pulse-generating lasers the cavity has to be designed to optimize the pulse duration (i.e. to provide short pulses) and/or the repetition rate. For example, in mode-locked lasers, the cavity lengths directly defines the pulse repetition rate. This means that in order to obtain the desired high pulse intensity, the cavity has to be of a much greater size for pulse generating lasers than for the laser of Kasamatsu. More generally, there are fewer degrees of freedom available to the designers of pulse-generating lasers.

For these reasons, cw lasers and pulse-generating lasers are completely different fields, in which different search groups are active, which concern different laser manufacturing industries etc. For example, the assignee of this application is a manufacturer of pulse generating lasers and would not have the know-how for fabricating a competitive cw laser. The expert in the field of pulse-generating lasers would thus never consider the Kasamatsu reference. However, even if we were to assume for sake of discussion that he would, the following comments would apply.

The examiner correctly points out that Weingarten discloses a semiconductor saturable absorber mirror (SESAM) for passive mode locking of a resonator. However, the laser shown by Weingarten is merely a low average output power pulse generating laser.

In fact, SESAMs as such have been known in the art for several years now. However, the expert has *no motivation whatsoever* to introduce such a SESAM into the laser device of Kasamatsu. SESAMs are exclusively useful for mode-locking in pulsed lasers. Introduced in a cw laser such as Kasamatsu's, they would inevitably render the laser unusable. None of the cavity design parameters would be suited for a pulse generating laser (see the description by Kasamatsu on pages 1879-1880). Additionally, SESAMs bring about losses (saturable and non-saturable losses). They also are delicate parts which tend to be thermally damaged quite easily.

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Compared to the teaching of Kasamatsu, a cavity for a *pulse generating laser* would have to be redesigned from scratch in order to function properly.

More generally, the expert will *not consider* introducing a saturable absorber in a high average output power laser such as a cooled-thin-disk-laser. The reasons for this are set out on page 4 of the specification of the present application. They are also described in the German patent application publication DE19907722, mentioned at page 4 of the specification. Lines 17-30 of Column 2 of this publication translate as follows:

> For laser systems with high power (some 100mW) and on another basis (cf. e.g. EP0492944A2) a method for passively mode locking by means of a Kerr lens device was provided, wherein no hints towards an application in high power laser systems with ultra-short pulses can be found, though. Rather, further progress has been achieved using semiconductor based saturable absorbers (SESAMs), which, however, have proven to be too short-lived for high power laser systems, regarding their applicability for powers above some 100mW. On the other hand, non-linear optical methods are preferred, since they are power scaleable by means of appropriate focussing of the beam, and since they do not rely on direct absorption of radiation.

It is an *achievement* of this invention as defined in the independent claims to have *considered and reduced to practice* introducing saturable absorbers into a laser with a laser gain medium having two end faces, and at least one of said end faces comprising a cooling surface, i.e. a laser being designed for high power operation.

For all these reasons, reconsideration is requested.

Respectfully submitted,

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to be converted by means of a parametric oscillator or Raman cell (Chap. 10). An alternative approach for eyesafe rangefinders is based on flashlamp or diode pumped Er:glass lasers which directly emit at the desired wavelength. The most popular method of Q-switching such lasers is the rotating Porro prism. However, recently, passive Q-switches based on uranium doped CaF_2 have been developed for this laser [8.87, 88].

8.6 Cavity Dumping

A means for generating extremely short Q-switched laser pulses involves Q-switching the laser with 100 % mirrors on both ends of the cavity and then, at the peak of the circulating power, rapidly switching the output mirror from 100 to 0 % reflection. This leads to a rapid dumping of the entire optical energy from within the cavity. One of the advantages of this technique is the production of Q-switched pulses whose width is primarily a function of the oscillator cavity length, rather than the gain characteristics of the laser medium. Specifically, the laser pulse width at the half-power points will be equivalent to the round-trip transit time in the cavity, with the condition that the Q-switch employed be switched within this same time period. Thus, based on allowable cavity dimensions, pulse widths in the range of 2 to 5 ns are feasible for oscillators whose pulse widths are of the order of 10 to 20 ns in the normal Q-switch mode.

Figure 8.31 shows the optical layout of a ruby oscillator employed to generate short pulses by the cavity dumping mode. We will explain the operation of the system by assuming that the ruby c plane is perpendicular to the plane of the paper. When the flashlamp is fired, the horizontally polarized ruby fluorescence is transmitted by the thin-film or calcite polarizer, thereby preventing regeneration. Upon reaching peak-energy storage in the ruby, the Pockels cell is biased to its half-wave retardation voltage. The resulting vertically polarized light is reflected by the polarizer to the off-axis mirror, and regeneration occurs in the cavity. When the power in the cavity reaches its peak value, the bias is removed from the Pockels cell in a time period of about 2 ns. The cavity energy then literally drains out of the cavity in the time required for the radiation to travel one round trip in the optical cavity. The combination of the polarizer, Pockels cell, and 100 % mirror comprises what amounts to a high-speed voltage-variable mirror whose reflectivity is changed from 0 during the pumping cycle to 100 % during the pulse buildup, and back to 0 during the cavity dumping phase.

To illustrate the practical realization of this technique, we will consider a typical ruby oscillator consisting of a 10-cm by 1-cm ruby rod, a Pockels cell, a thin-film polarizer, and two 99 % mirrors. If we assume a 75-cm-long cavity, we obtain a round-trip transit time of 5 ns. The ruby rod is pumped by a 1-ms-long flashlamp pulse, and the Pockels cell is switched the first time after about 0.8 ms. The time delay between switching the Pockels cell and the occurrence of peak power in the cavity is typically 60 ns. In order to extract the stored cavity energy,

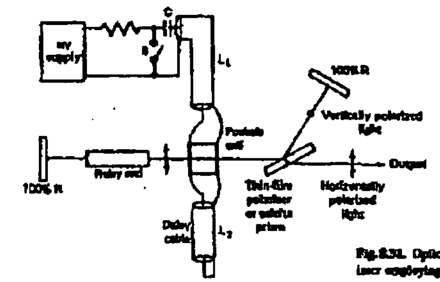


Fig. 8.31. Optical layout of a ruby laser employing cavity dumping

the bias on the Pockels cell is reduced to zero after this time delay. This can be accomplished by means of the circuit shown in Fig. 8.31. In this arrangement, the Pockels cell is connected in-line between coaxial cables L_1 and L_2. Closing the switch S will discharge the capacitor C into the transmission line L_1. When the voltage pulse reaches the Pockels cell, the optical beam will experience a 90° polarization rotation and the Q-switch pulse will start to build up from noise. Assuming a perfect 50 Ω impedance of the Pockels cell, no reflection will occur at the cell and the voltage pulse will travel to the end of the shorted transmission line L_2. At that point the pulse will be reflected with a 180° phase shift. When the reflection reaches the cell, the voltage on the crystal will be zero. Therefore the length of cable L_2 determines for how long the voltage is applied to the Pockels cell.

The performance of a ruby oscillator having the above-mentioned system parameters is illustrated in Fig. 8.32. Shown is the power inside the resonator if the energy is not dumped (Fig. 8.32a). The measurement was made by monitoring the leakage radiation through one of the 99 % mirrors with a fast detector and oscilloscope. The peak power and energy inside the resonator were determined to be 190 MW and 1 J, respectively. Figure 8.32b depicts the circulating power monitored through the same mirror if the energy is dumped and the system is operated as a PTM oscillator. The internal cavity power reaches almost the same value as in Fig. 8.32a, then falls in about 5 ns to almost zero. This reveals that all but a small percentage of the available energy has been dumped from the cavity. Figure 8.32c reveals that the dumped pulse is triangular, with a 10 to 90 % rise time of 3.0 ns and a pulse width of 5.3 ns. This width compares exactly with the cavity round-trip transit time within experimental error. The total energy of this pulse was measured to be 0.75 J. The peak power of this pulse is thus 1.4×10^8 W. The rise time of the output pulse is determined by the switching speed of the hydrogen thyratron which was used to discharge capacitor C. The experimental data reveals that 75 % of the stored energy was extracted from the resonator.

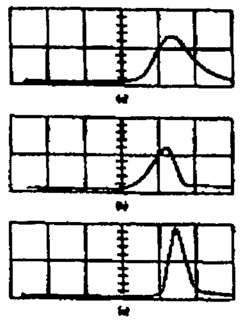


Fig. 8.32a–c. Performance of a ruby oscillator with cavity dumping. Photo scales 10ns/div. (a) Internal cavity power at 99% mirror without dumping. Pulse rise time 7ns, pulse width 12ns, peak power 190MW. (b) Internal power, with cavity dumping, drops from 190MW to almost zero in 5ns. (c) Power dumped from cavity; rise time 3.0ns, pulse width 5.3ns, energy 0.74J, and peak power 140MW

In practical situations the design of cavity dumped lasers is completely dominated by the requirement of keeping the power density within the cavity below the damage level. The usual calcite polarizer, being the component with the lowest damage threshold, has been replaced in contemporary oscillators by highly damage-resistant thin-film polarizers. These components permit oscillators to operate at power densities up to 300 MW/cm^2.

It is not necessary in a cavity dumped system to use the same Pockels cell for both the Q-switch initiation and cavity dumping. Earlier systems employed two Pockels cells for these functions [8.89–91]. Also, instead of a fixed-delay transmission line a more precise synchronization between the peak power in the cavity and the switching of the Pockels cell can be achieved if the cavity radiation is monitored by a detector mounted behind one of the 99% mirrors [8.92]. Other variations of cavity dumping are described in [8.93–95], this technique can be employed in any solid-state laser; for example, Nd:glass oscillators have produced 3-ns pulses with energies up to 180 mJ [8.95]. Further examples of cavity dumped systems are given in Sects. 9.3.2 and 9.4.2 in connection with diode-pumped actively mode locked oscillators or with regenerative amplifiers. Cavity dumping is also possible with cw-pumped lasers; this will be discussed next.

Cavity Dumping of CW-Pumped Lasers

Cavity dumping can be compared with the Q-switching of a continuously pumped laser. In both cases energy is assumed to be discharged from the laser in the form of a repetitive train of light pulses. However, energy accumulation and storage between output pulses are primarily in the optical field for cavity dumping, and primarily in the population inversion for Q-switching.

The finite buildup time of the field inside the laser cavity and the time required to repump the inversion set an upper limit to the repetition rate available from Q-switched lasers. This maximum value of repetition rate for Q-switched Nd:YAG lasers is of the order of 50 to 100 kHz. Cavity dumping of continuously pumped lasers is a way to obtain pulsed output at higher repetition rates than are available by Q-switching. Repetition rates from 125 kHz up to several megahertz for cavity dumping were achieved with cw-pumped Nd:YAG lasers [8.96, 97].

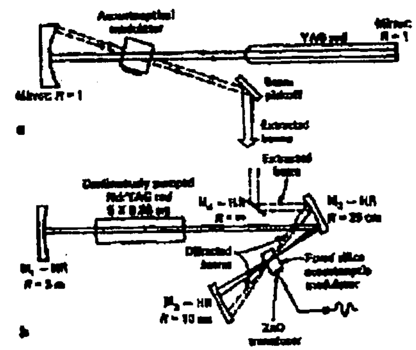


Fig. 8.33. Common arrangements for cavity dumping of cw-pumped solid-state lasers. The broken lines indicate the beams which are diffracted by the modulator

Figure 8.33 exhibits two common arrangements employed for cavity dumping of cw-pumped solid-state lasers [8.96, 97]. Essentially all systems of this type employ acoustooptic modulators as the switching element. In order to obtain fast switching action, the incident beam must be focused to a narrow waist inside the modulator. The two oscillator designs differ in the way the optical beam is focused into the modulator.

In Fig. 8.33a the modulator is located at a beam waist created by a concave mirror and by the thermal lens properties of the laser rod. The acoustic wave in the fused silica causes Bragg scattering of the forward- and backward-traveling light beam in the resonator. The two diffracted beams which are obtained from the cavity-dumped oscillator are initially traveling in opposite directions, therefore their frequencies are shifted to a value of $\omega + \Omega$ and $\omega - \Omega$, where ω is the frequency of the incident beam and Ω is the frequency of the acoustic wave [8.98, 99]. The two diffracted beams are extracted from the cavity as a single beam and deflected out of the system by a mirror. In Fig. 8.33b the cavity is

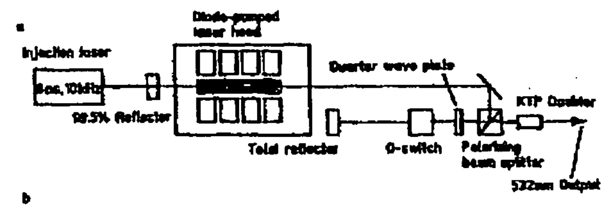
formed by three high-reflectivity mirrors M_1, M_2, and M_3. The mirror curvature and the distance between M_2 and M_3 are chosen such that the light beam between M_2 and M_3 is focused to a small diameter at the center of curvature of M_3. The modulator is inserted at the waist of the optical beam.

Acoustooptic modulators employed for cavity dumping differ from their counterparts used in Q-switch applications in several respects:

1) Compared to Q-switching, the cavity-dump mode requires much faster switching speeds. The rise time in an acoustooptic modulator is approximately given by the beam diameter divided by the velocity of the acoustic wave. In order to obtain rise times around 5 ns, a value which is required for efficient cavity dumping, the incident beam must be focused to a diameter of approximately 50 μm.
2) For efficient operation in the cavity-dump mode, it is important that essentially all the circulating power be diffracted into the first diffraction order. In a Bragg device the diffraction efficiency increases with the rf carrier frequency, therefore modulators employed in cavity dumpers operate at considerably higher frequencies, i.e., 200 to 500 MHz as compared to acoustooptic Q-switches.
3) In order to generate an output pulse in the cavity-dump mode, a short rf pulse is applied to the modulator, whereas in an acoustooptic Q-switch the rf carrier is turned off for the generation of an output pulse.
4) The cavity is never kept below threshold condition as in the Q-switched mode of operation. If the cavity is dumped of all its energy, the field has to build itself from the noise level. Repetitive cavity dumping was observed to become unstable in this case. If the repetition rate is lowered, the laser material is pumped higher above threshold between pulses, therefore, a larger fraction of the stored energy is extracted from the system (see Sect. 8.1). The lower limit of the dumping repetition rate is reached when the internal laser energy decreases to one photon immediately after dumping. The upper limit of the cavity dumping repetition rate is set by the switching speed of the modulator. Repetition rates as high as 10 MHz have been reported. From a cw-pumped Nd:YAG laser capable of 10 W of cw power, peak powers of 570 W with a pulse duration of 25 ns have been obtained at a 2 MHz repetition rate [8.100]. For high-data-rate communications systems, cavity dumping of cw-pumped lasers is sometimes combined with mode locking [8.101, 102].

The technique of cavity dumping is also employed in regenerative systems. In a regenerative laser a pulse is injected into a laser resonator containing an amplifier. The pulse passes several times through the same amplifier medium and is then switched out. Figure 8.34a shows an optical schematic of a laser which employs this technique [8.103]. Illustrated is a diode-pumped Nd:YAG crystal located between two highly reflective mirrors, a Pockels cell Q-switch and a polarizer. The Nd:YAG crystal is cw-pumped and repetitively cavity dumped at a 10 kHz repetition rate. During the 100 μs pump time, the Pockels cell is

a



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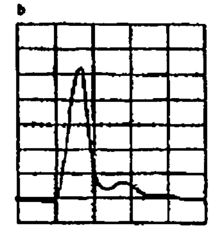

Fig. 8.34a,b. Cavity dumping of an injection seeded laser. Optical schematic of laser system (a) and output pulse shape (b)

operated at zero wave retardation. This is the low Q-condition because radiation is transmitted out of the resonator through the polarizer. At the end of the pump pulse, the injection laser seeds a 8 ns pulse into the resonator through the rear reflector. At the same time, the Pockels cell is switched to 1/4 wave retardation which establishes the high Q-condition. Radiation is building up between the two highly reflective mirrors. The injected pulse is regeneratively amplified in the cavity for about 360 ns or 120 passes. The Q-switch is then returned to zero wave retardation which dumps the amplified pulse through the polarizer. The KTP crystal converts the wavelength to 532 nm and shortens the pulse to about 5 ns. The sequence is repeated at a 10 kHz pulse repetition frequency. Figure 8.34b displays the output pulse at 532 nm.

An analysis of the extraction efficiency of cavity-dumped regenerative lasers can be found in [8.104]. The results are quite similar to the Q-switched case, and the extraction efficiency depends only on the amplifier gain and resonator losses.